Supernova & Stellar Feedback

Dave Strickland (JHU), James Bullock (UC Irvine), Tim Heckman (JHU), Crystal Martin (UCSB), Andy Ptak (JHU), Eric Schlegel (UT San Antonio), Daniel Wang (UMass)

What is stellar/supernova feedback?

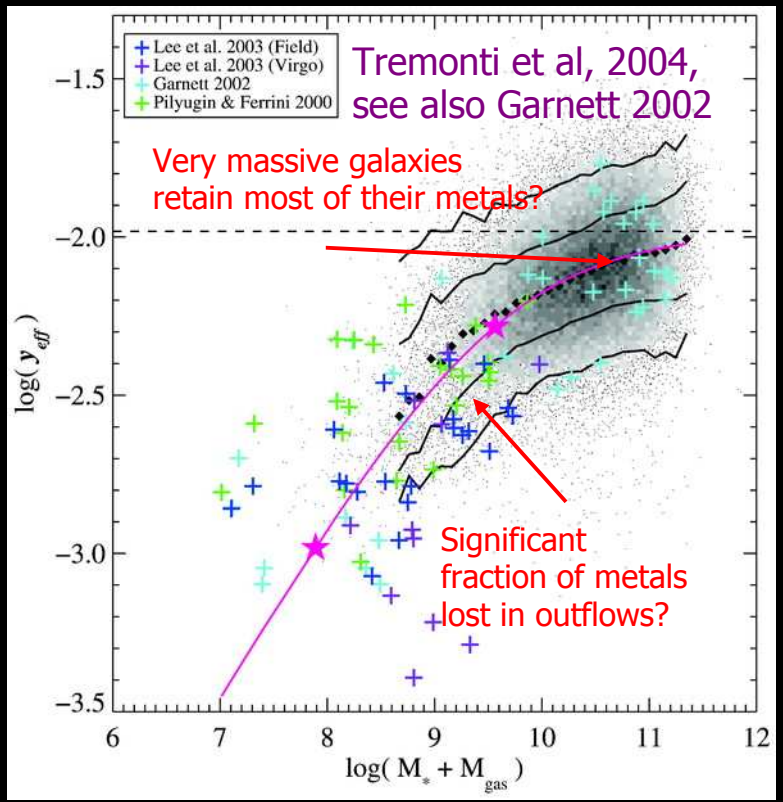
- Feedback is the return of energy (mechanical or radiative) and metal-enriched gas from stars back into the ISM.
  - "Mechanical feedback" via SNe/winds generates plasma with $10^6 < T(K) < 10^8$. It is the primary generator of the hot phases of the ISM in normal galaxies.
  - "Radiative feedback" via ionizing photons also physically important, but not for X-ray astronomy.
- Most significant sources of star-related feedback:
  - Core collapse Sne (massive stars).
  - Type Ia Sne (generally older stellar population).
  - Stellar winds from massive stars (equivalent mass return to CC Sne).
- Panel focus is on feedback and hot ISM at *galactic scales*.
  - Hot ISM in galaxies, in their halos, and outflows (galactic winds) to the IGM.
  - Starburst galaxies, normal star-forming galaxies, low SF rate spiral galaxies.

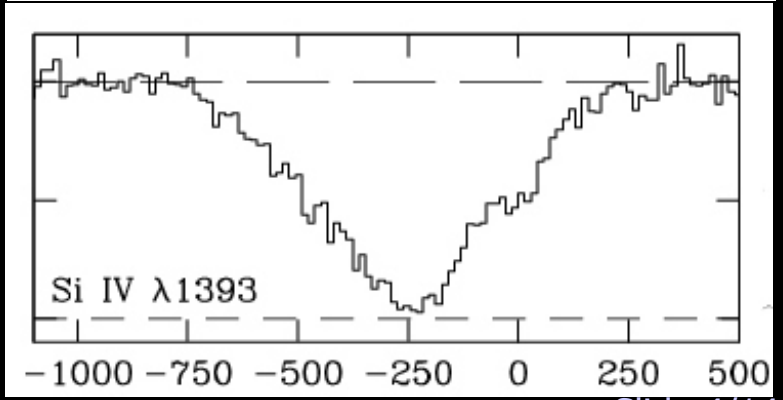
X-rays provide natural & unique insight

- Energy and metals from feedback process initially deposited in the hot (log T = 6 - 7) or very hot (log T > 7) phases
  - Fast shock: $T_{sh} \sim 5 \times 10^6 (v_{sh}/600 \text{ km/s})^2$ K.
- For starburst-driven superwinds (with ram-or-radiatively accelerated clouds):
  - Injected energy per particle equivalent to T ~ efficiency x 10^8 K, v ~ 2600 x $(\text{efficiency})^{0.5}$ km/s.
  - Majority of energy remains in KE of hot/v.hot phases.
  - $V_{HOT} > v_{WIM}$ or v_{WNM} (WIM/WNM is not a direct tracer of the wind).
- Depth of galactic potential wells corresponds to soft X-ray energies
  - Virial temperature $T_{vir} \sim 10^6 (v_{rot}/200 \text{ km/s})^2$ K.
  - "Escape" temperature $T_{esc} \sim 5 \times 10^6 (v_{esc}/600 \text{ km/s})^2$ K.

Why is stellar feedback important?

- [old view] Affects faint-end of galaxy LF.
- IGM metal enriched, but by what?
  - Log Z_{IGM}/Z_{sun} ~ -2 to -3 at z ~ 2 (Bouche et al 2007).
  - Log Z_{IGM}/Z_{sun} ~ -1 at z ~ 0.
- Galaxy M-Z relationship (e.g Tremonti et al 2004)
- SN-driven winds common in SFing galaxies (Heckman et al 2000; Adelberger et al 2003).
- Feedback a fundamental aspect of current models of galaxy formation/evolution.





Outflow from MS1512-cB58 at z = 2.73
Pettini et al (2002).

Outstanding issues

- Temperature/phase/ionization structure of the hot (and v.hot?) plasmas
  - Clearly defined phases vs DEM (1-T, 2-T, multi-T?).
  - What physically determines temperature distribution in/around galaxies?
  - CIE vs NIE vs recombining plasma.
  - Forward fitting of simplistic spectral models vs true line-based diagnostics.
- Elemental abundances and the origin of the X-ray-emitting plasmas.
  - No consensus over whether absolute abundances from CCD spectra accurate.
    - Possibly alpha/Fe enhanced plasma in starburst galaxies.
    - Fe-enhanced plasma in low SF/bulge-dominated disk galaxies.
  - Tracing patterns of element enrichment/redistribution.
- Hot gas kinematics
  - No current measurements of hot gas velocity in galaxies other than MW!

Panel deliberations

- Temperature/phase/ionization structure:
  - Physically interesting to X-ray astronomers, but...
  - *Current estimates of gas temperatures hardly different from early 90's.*
  - *Non-direct, model-dependent relationship to feedback theory.*
- Elemental abundances in normal galaxies:
  - Again, very important within the field, but...
  - *Unlikely general astrophysical community aware of controversy.*
  - *Contamination issues due to low spatial resolution (esp. within disks)?*
- Hot gas kinematics:
  - Fundamentally new.
  - Kinematics for superwinds very important for testing theories.
  - Simple, direct implications even without detailed theoretical models.
  - *Potentially difficult given relatively low resolving power of XMS.*

Probing hot gas kinematics with Con-X

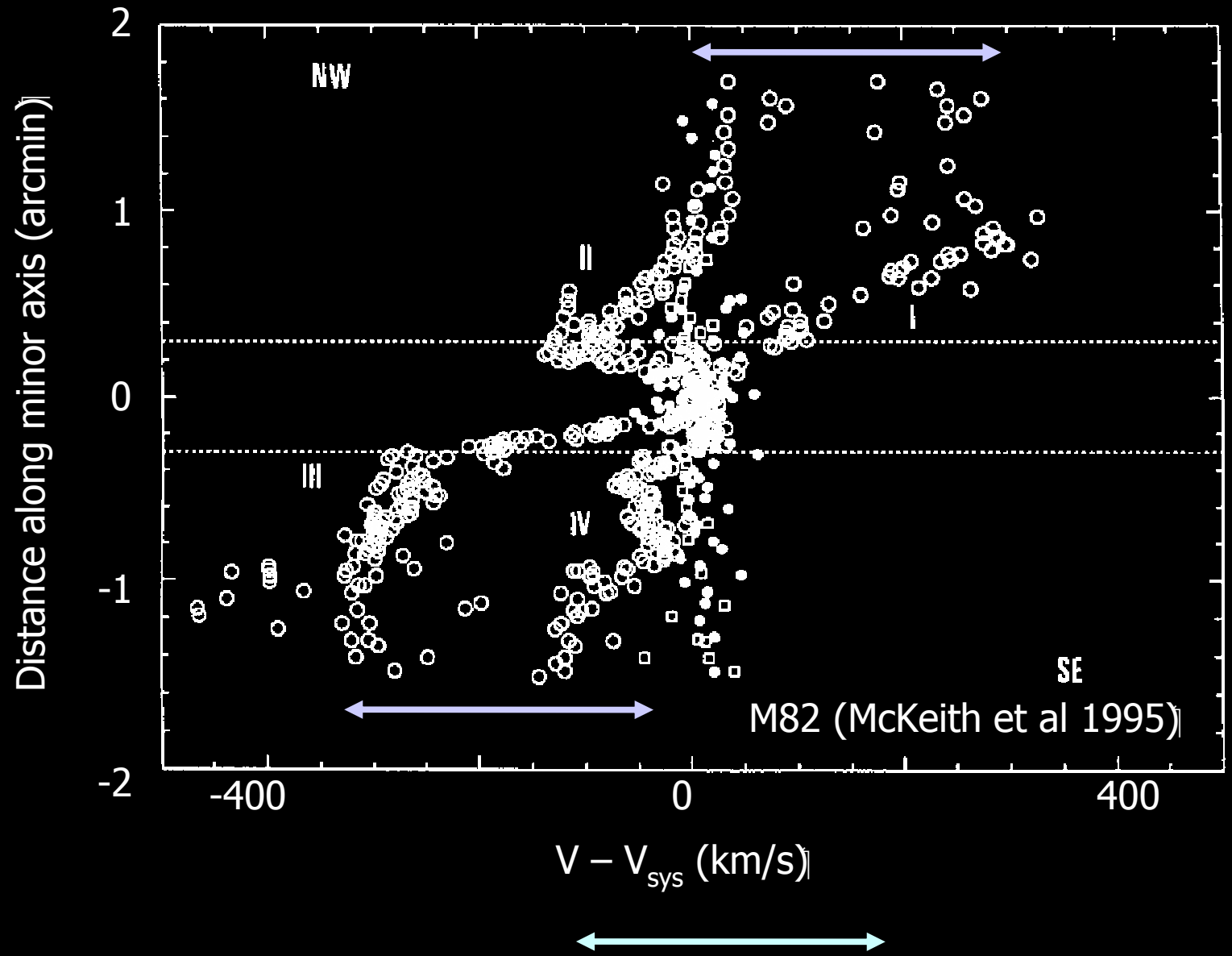
- Calorimeter or grating?
  - Grating ideal for MW/LMC absorption-line studies using AGN and/or LMXBs as BG sources (e.g. Bregman, Wang).
  - Absorption line studies of superwinds -> require good BG srcs. (WHIM panel overlap)
  - *Emission line studies of extended diffuse gas (e.g. Halos, superwinds) -> Calorimeter.*
- Targets for Calorimeter-based studies of hot gas kinematics
  - Edge-on or face-on galaxies with known diffuse X-ray emission, O(30) targets.
- Methods
  - Redshift of lines wrt systemic (centroiding).
  - Line broadening or splitting due to outflow/rotation (line widths).

Line offsets and line splitting/breadth

Optical emission lines from roughly edge-on starbursts with winds:

(1) Lines split/broadened by divergence of flow.

(2) Lines offset from galaxy systemic velocity.



Line offsets and broadening cntd.

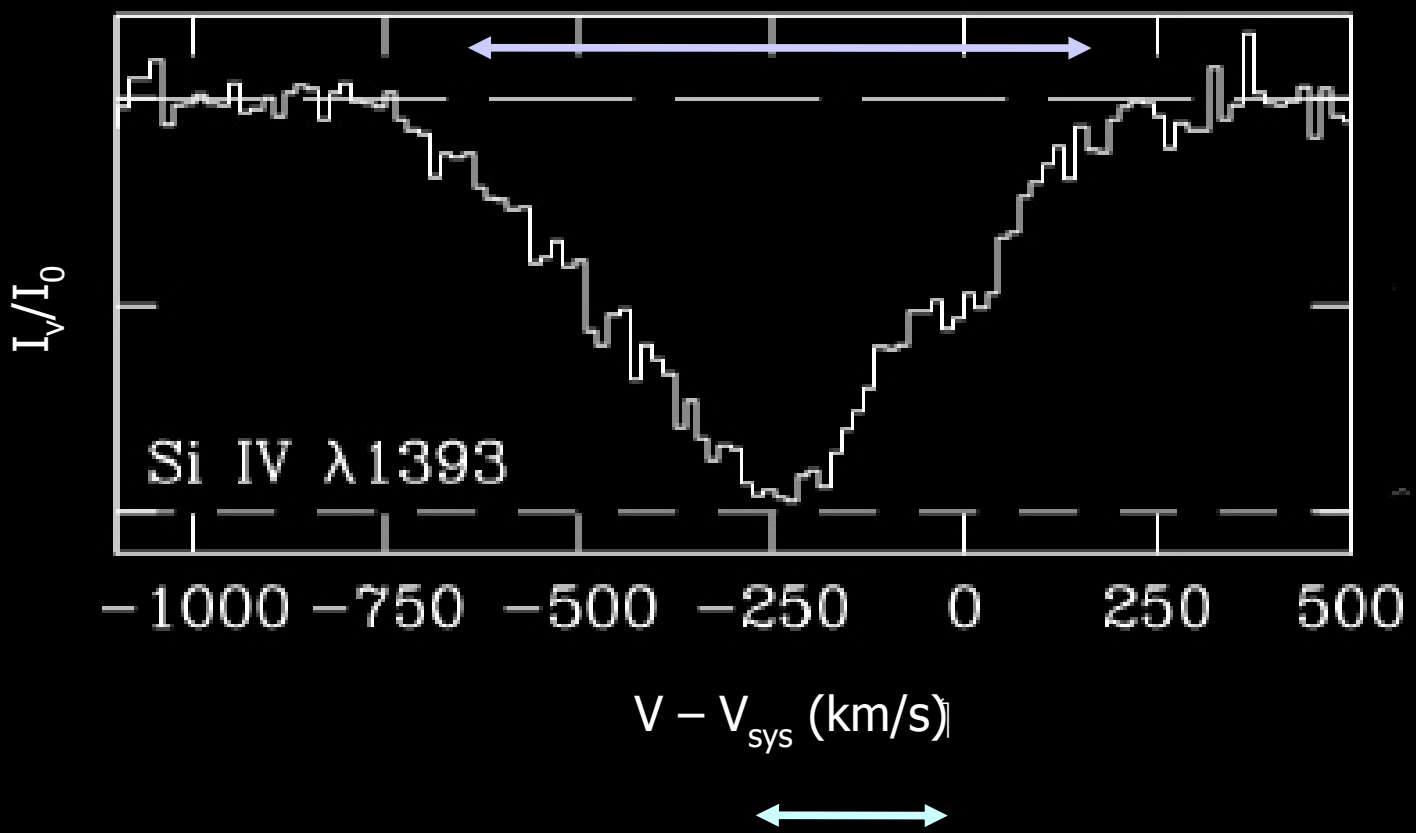
Optical/UV absorption lines from roughly face-on starbursts with winds:

(1) Broad lines

(2) Line centroid offsets to blue from galaxy systemic velocity.

Again, typical optical/UV line offsets and widths several hundred km/s.

MS1512-cb58 (Pettini et al 2002)



Required velocity sensitivity

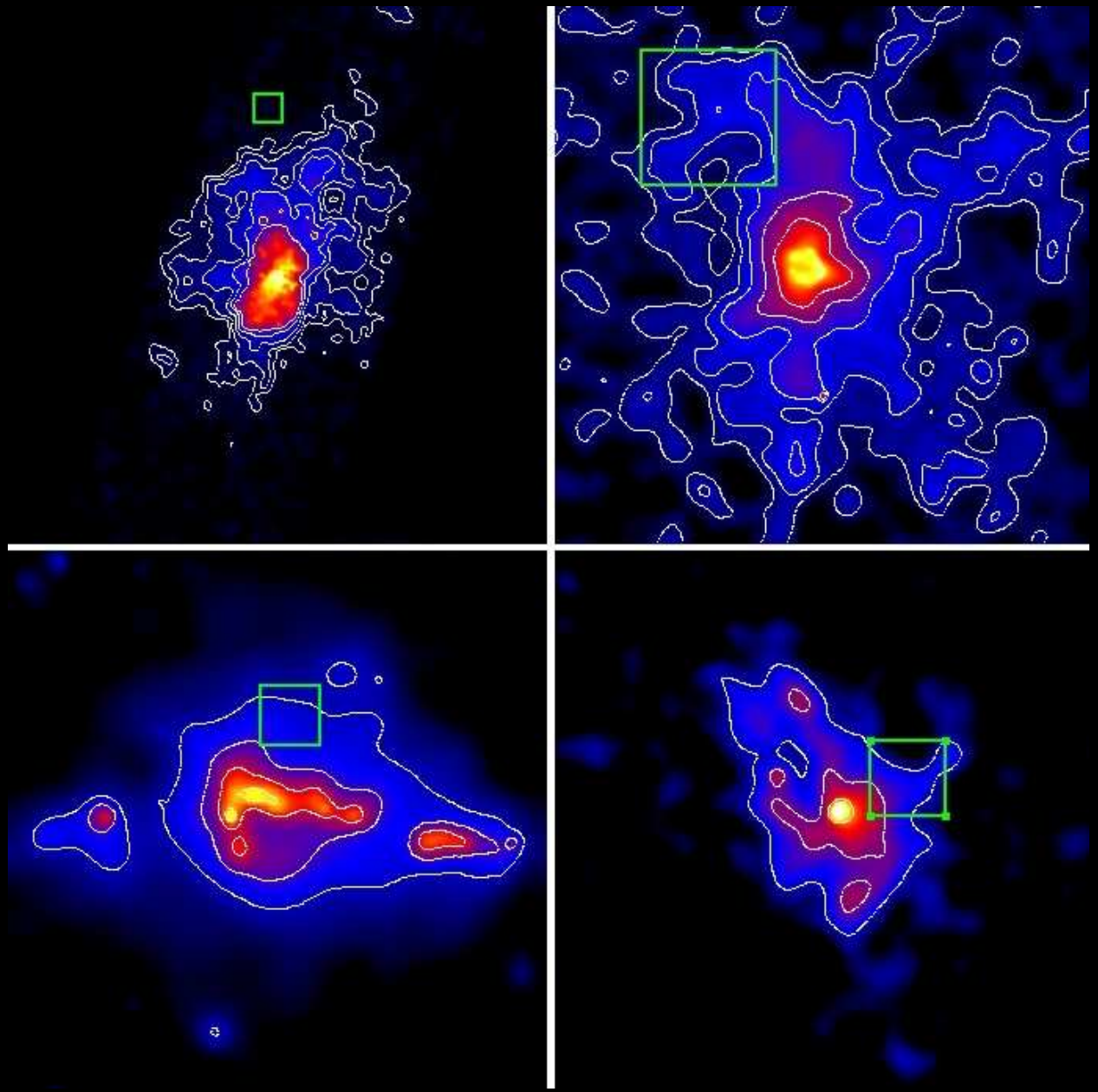
- Characteristic velocities of order rotational or sound speed.
  - Rotation of gas in galactic fountains [NGC 891], v ~ v_{rot} ~ 200 km/s.
  - Velocity of gas in superwinds (optical), v ~ 2-3 x v_{rot} ~ 200 – 600 km/s.
  - Sound speed of 0.6 keV plasma [Sombrero galaxy] v ~ 400 km/s.
  - Possibility that v_{HOT} > 1000 km/s in superwinds.
- However, line of sight velocities will be LOWER.
  - Typical v_{LOS} ~ v/2, so require sensitivity to 100 - 150 km/s.
  - For N-sigma measurement, requires σ_v ~ (100 to 150)/N.
  - 5 sigma measurement want line centroids accurate to ~ 20 – 30 km/s.

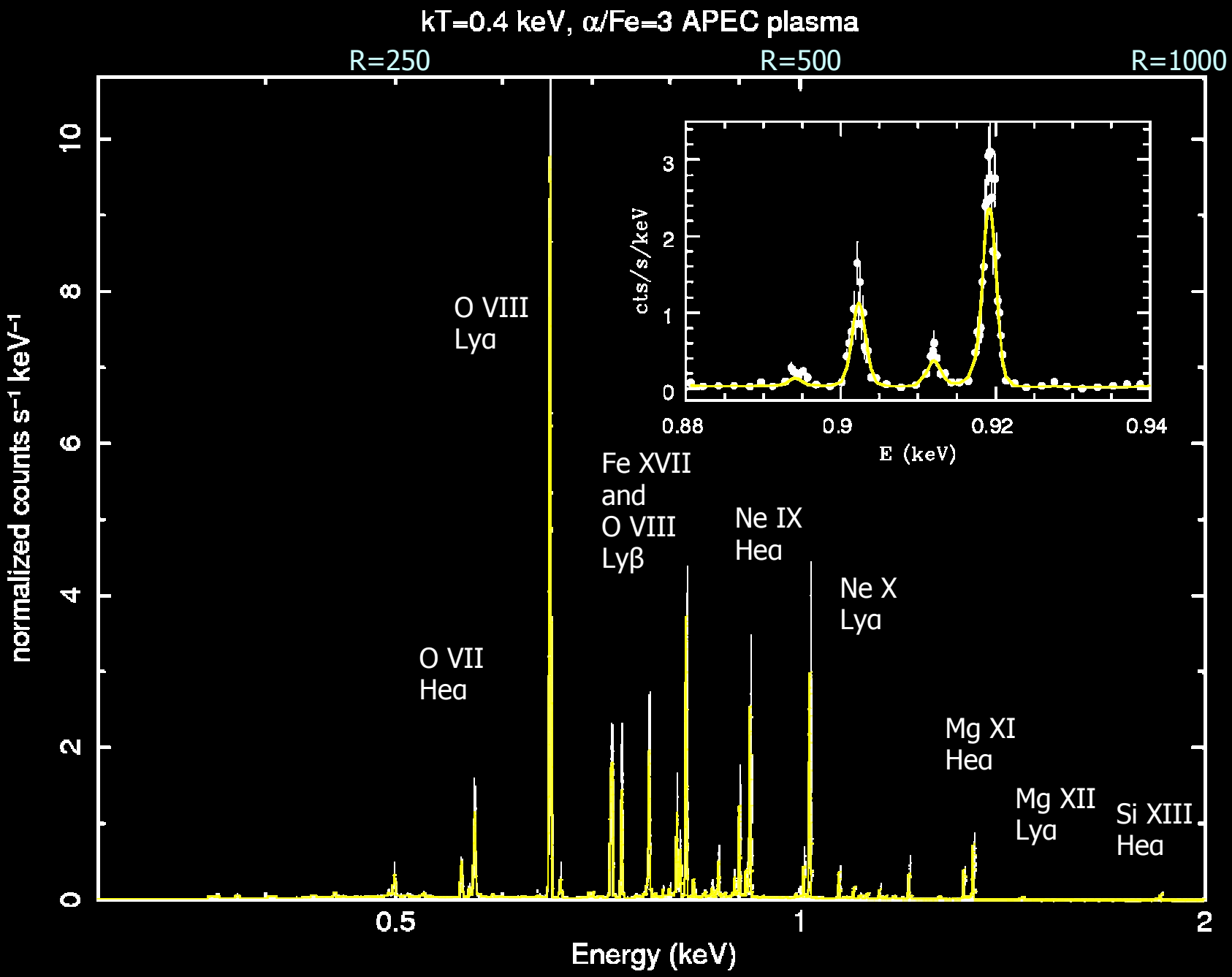
Simulations

How accurately can we determine line widths and centroids for faint diffuse thermal emission?

Simulate kT=0.4 keV α/Fe=3 APEC plasma typical of extended halos of both normal and starbursting spiral galaxies.

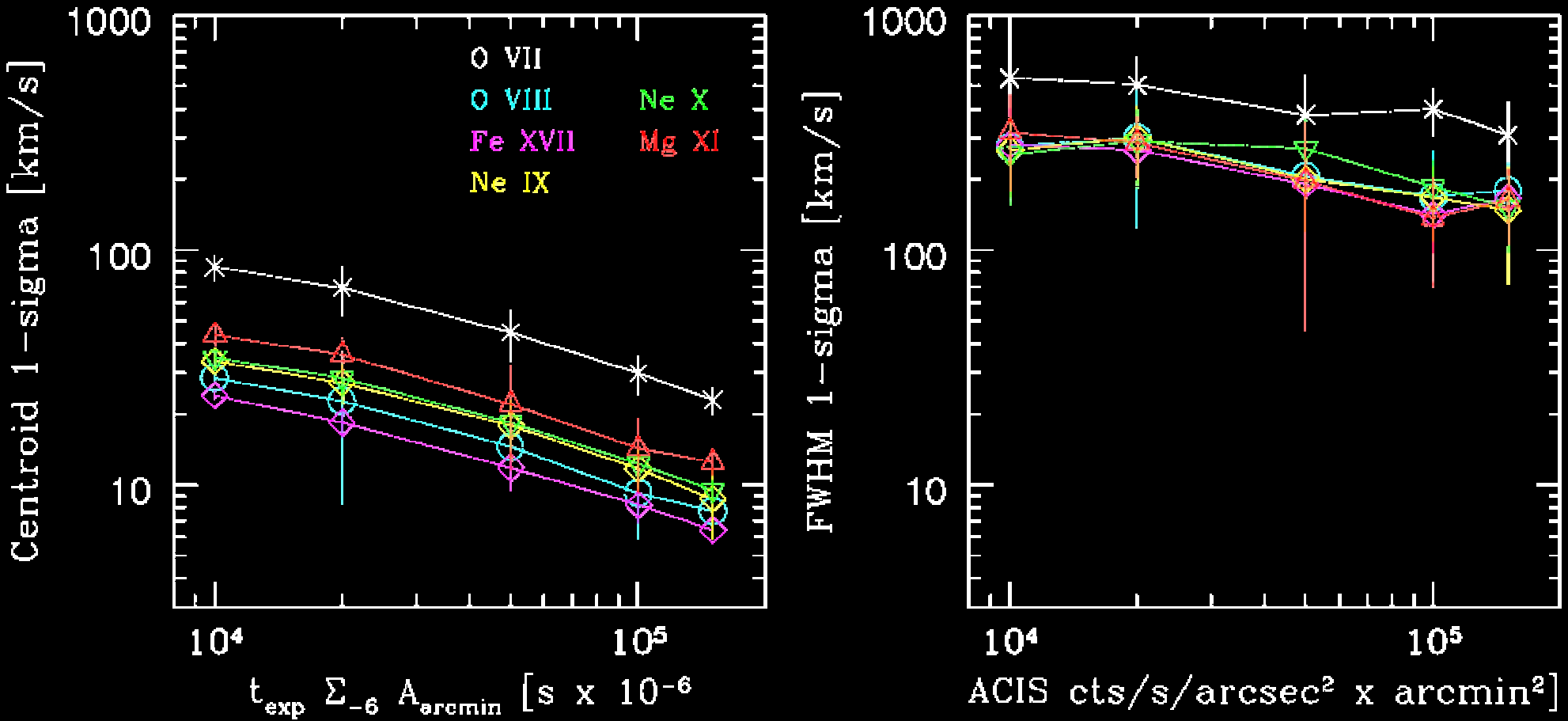
1x1 arcmin □
$\Sigma_{ACIS} = 10^{-6}$ cts/s/arcsec^2




kT=0.4 keV, α/Fe=3 APEC plasma
R=250
R=500
R=1000
normalized counts s⁻¹ keV⁻¹
Energy (keV)
O VIII Lyα
O VII Heα
Fe XVII and O VIII Lyβ
Ne IX Heα
Ne X Lyα
Mg XI Heα
Mg XII Lyα
Si XIII Heα
cts/s/keV
E (keV)

Results: Calorimeter velocity sensitivity

Response: conx-ea-101106-0p2.rsp



Caveats: (1) No background assumed. (2) Need to model in uncertainty in energy scale (a) between Calorimeter “pixels” and (b) between different observations.

Summary / To Do list

- Constellation-X offers ***unique*** access to kinematics (and hence energetics) of stellar feedback.
  - Stellar feedback responsible for hot phase of ISM in normal+starburst galaxies.
- Nearby normal/starburst galaxies, from zero to O(30) targets:
  - Redshift of lines can be determined to accuracies ~ 30 km/s in faintest regions of normal/starburst galaxies in < 100 ks exposures.
  - Good enough to well constrain outflows all but dwarfs (Δv_{los} ~ 100+ km/s), rotation in normal spiral halos (Δv_{los} ~ 100+ km/s).
- Calorimeter-based studies:
  - Redo simulations with more realistic noise (BG and energy scale).
  - Concrete target list.
- Panel to include Grating-based studies?
  - Firm up MW/LMC AGN/LMXB numbers?
  - Number for AGN behind edge-galaxies?
- Write-up for Decadal survey.

Absorption line studies of the MW/LG

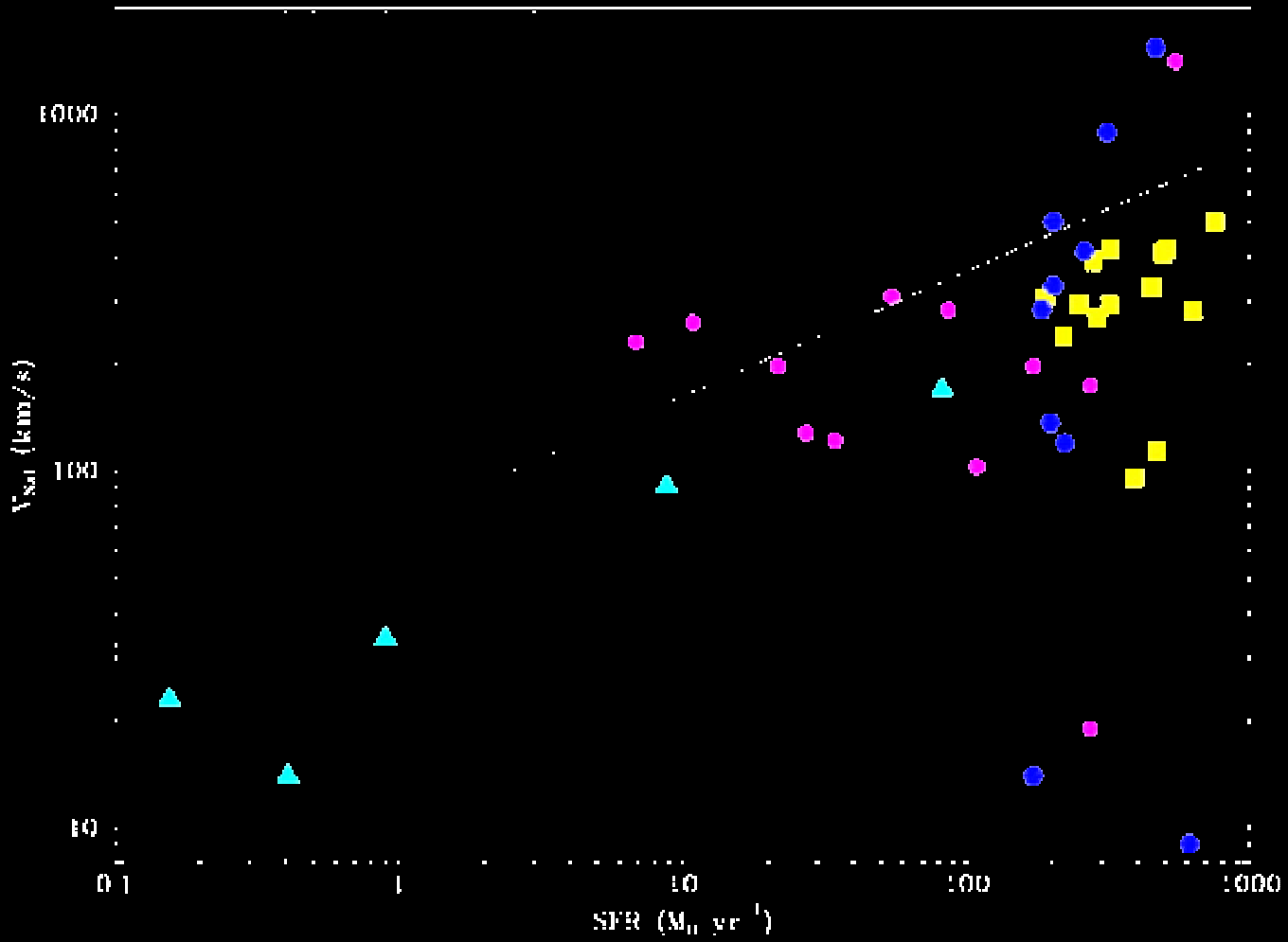
- Existing X-ray absorption line studies of MW/local group hot gas (e.g. Wang & Yao 2005; Yao & Wang 2007; Bregman & Lloyd-Davies 2007)
  - Number of AGN ~10 - 20
  - Number of LMXBs (L > 1038 erg/s) ~ 10
  - Curve of growth based analysis, velocity dispersion accurate to factor 2.
- With factor 100 increase in area at 20 Angstrom expect factor 1000 increase in number of AGN observable.
- Should be able to study LMXBs with equivalent S/N as current 20 ks Chandra grating studies down the LX ~ 1036 erg/s, factor ~10 more sources.

Range of velocities expected (1)

Current optical "state of the art": Na I doublet WNM absorption lines.

Line-centroid blue shifts for dwarf starbursts, L_{IR}^{*} starbursts, LIRGs and ULIRGs span range 30 – 1000 km/s.

Expect velocities in X-ray to be ≥ than $V_{opt/UV}$.



From Martin (2005)

Range of velocities expected (2)

- Starburst-driven superwinds:
  - Roughly face-on starburst, LOS centroid vNaD ~ 200 (SFR/10)$^{\sim 1/3}$ km/s.
  - Roughly edge-on starburst, LOS centroid ΔvHa ~ 100 – 500 km/s (HAM90).
  - Velocity of soft X-ray emitting gas may be proportional to optical, or higher and non-proportional.
  - Near starburst region, 6.7 keV iron line, v ~ 1000 km/s (c_s at 4 x 10^7 K).
- Halos of normal spiral galaxies:
  - Rotation in the halo of NGC 891: ΔvHI ~ 200 km/s (Oosterloo et al 2007).
- Subsonic winds from galactic bulges (SN Ia-driven flows):
  - V_x < 400 km/s (c_s for kT=0.6 keV, Sombrero galaxy, Li et al 2007),